Modelling of radio emission from normal galaxies at low radio frequencies

Wojciech Jurusik*, Krzysztof T. Chyzy

Astronomical Observatory of the Jagiellonian University, ul Orla 171, 30-244 Krakow, Poland
e-mail: jurusik@oa.uj.edu.pl, chris@oa.uj.edu.pl

Abstract

In this paper we present results from modelling of the low frequency radio emission from galaxies with similar characteristics to the Milky Way with represantive distance of 1 Mpc. In modelling we considered observational effects as galaxy orientation (inclination). Results are presented in the form of global and local (from galaxy centre) spectrum. The radio emission of normal galaxies may become opaque at low frequencies due to thermal ionized gas. According to our results ionized gas similar to the Milky Way ionized gas may be responsible for flattening of radio spectra. We argue that global spectra from galaxies do not change their shape at higher frequencies with disk orientation along the line of sight even in galaxies with higher thermal fractions. Only the low frequency part of total spectrum is sensitive to galaxy inclination. The flattening of total radio spectrum seems to be more possible in edge-on than face-on galaxies. We also show that the local spectrum from galaxy center has clear turn-over at a few MHz only for galaxies with higher inclination.

1 Introduction

During the last decades the radio continuum emission from great variety of galaxies with different morphological types were studied extensively at higher radio frequencies. The first systematic studies of spiral galaxies radio contunuum were performed by Klein & Emerson (1981)[1], Hummel (1981)[2], Gioia et al. (1982)[3] and Harnett (1982)[4]. Later the number of galaxies were observed with the VLA at 1.49 GHz (Condon 1987)[5] and with the Effelsberg telescope at 10.55 GHz by Niklas et al. (1995)[6]. Multi-frequency systematic studies of radio continuum of galaxies led to the model of their radio emission. The cosmic rays electrons are accelerated in supernovae remnants, moving to the interstellar medium and are radiating in the present of the interstellar magnetic field. It is well known that radio continuum emission is directly connected with star formation activity and it is a sum of coexist processes non-thermal and thermal emission (synchrotron and free-free emission respectively). The synchrotron emission is by far the dominant process in the 1 – 10 GHz range, with a typical spectral index -0.8. The free-free emission becomes increasingly important at higher frequencies [7].

Previous and rare observational and theoretical research devoted to low frequency radio continuum emission from galaxies are often in contrary in conclusions. The first low frequency survey of 133 galaxies (68 galaxies detected) at 57.5 MHz was curried out by Israel and Mahoney (1990)[8]. Only the total integrated flux densities of detected galaxies were obtained due to low angular resolution of the survey. Measured luminosities of galaxies were lower than values extrapolated from high frequency data assuming constant spectral index. Interpretation of this discrepancy led to model that free-free absorption reduces part of synchrotron emission by a cool ionized gas (T_e <1000 K). Proposed correlation with the galaxy disk inclination that edge-on galaxies undergo the free-free absorption the most was refused later as a result of more extensive analysis of the same data by Hummel (1991) [9].

Galaxies with high star formation rate as sample of the Ultra Luminous Infra Red galaxies (ULRIGs) was studied at 1.46 GHz and 8.44 GHz with the VLA by Condon 1991 [10]. The deficit of radio emission at 1.46 GHz was found and interpreted as free-free absorption in ultraluminous nuclear starburst. Recently, a few ULIRGs were observed with the GMRT (Clemens et al. 2010 [11]). Radio spectra of observed galaxies reveal flattening, and turn-overs towards low frequencies.

In this paper we investigate global and local spectra from galaxies with moderate star formation rate, galaxies similar to the Milky Way. The free-free absorption is considered as a the only process, which may modify radio spectra at low frequencies. Correlation of radio spectra with galaxy orientation (inclination) and thermal fractions are taken into account in our modelling and discussed here.

2 Model

Realistic model of radio emission from normal galaxies with similar parameters to the Milky Way should take into account spatial distribution of cosmic ray electrons. We assumed disc component of the cosmic ray electron proposed by Sun et al. [12] represented by following spatial distribution:

$$C(R,z)=C_0\exp\left(-\frac{R-R_{SUN}}{8\,kpc}-\frac{|z|}{1\,kpc}\right) \quad (1)$$

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

The central region of galaxy cosmic ray electrons distribution for $R < 3$ kpc is taken as a constant C(R=3kpc) from the same reasons as in [12]. Constant C_0 is scaling factor responsible for the total non-thermal luminosity of modelled galaxy. Simple model of the ionized medium in the Galaxy proposed by Lyne et al 1985 [13] is adopted in our modelling and given by expression:

$$n_e(R,z) = \frac{2}{1+R/10}\left(0.025\exp\left(-\frac{|(z)|}{1000\ pc}\right) + 0.015\exp\left(-\frac{|(z)|}{70\ pc}\right)\right) \quad (2)$$

Model defined by equation (2) consists of two component: layer of approximately constant density 0.025 cm^{-3}, which mimics the warm ionized medium in the Galaxy and a thin layer of density 0.015 cm^{-3} with the height scale 70 pc, which represents distribution of H II regions smoothed out over space.

The above spatial distributions of the cosmic ray electrons and thermal emitting electrons are modelled over a grid (N*x*N*x*N) with resolution of 120 pc assuming distance of galaxy equal 1 Mpc, and radius 15 kpc. In each point of galaxy and along each line of sight the radiation transfer equation is solved depending on relative position of non-thermal emitting and ionized gas in each cell of grid. The out-coming radiation from single cell of grid (non-thermal or thermal or from well mixed thermal and non-thermal gas) may be partly absorbed by next cell along the line of sight by ionized gas at low radio frequencies. All contributions from each line of sight are summed, and both information about total emission and synthetic map of radio emission at each frequency are created. The global spectrum, local spectrum from galaxy centre, and synthetic maps of total power emission are obtained in frequency range from 1 MHz to 10 GHz. In our modelling observational effects as galaxy orientation (inclination) and spatial resolution of observations are taken into accont. We also focused on physical conditions as thermal fraction (thermal emission to total emission) in our approach.

3 Results

The total spectrum from our radio emission model from galaxy similar to the Milky Way for different inclinations and different thermal fractions at 1.0 GHz is depicted in Figure 1.

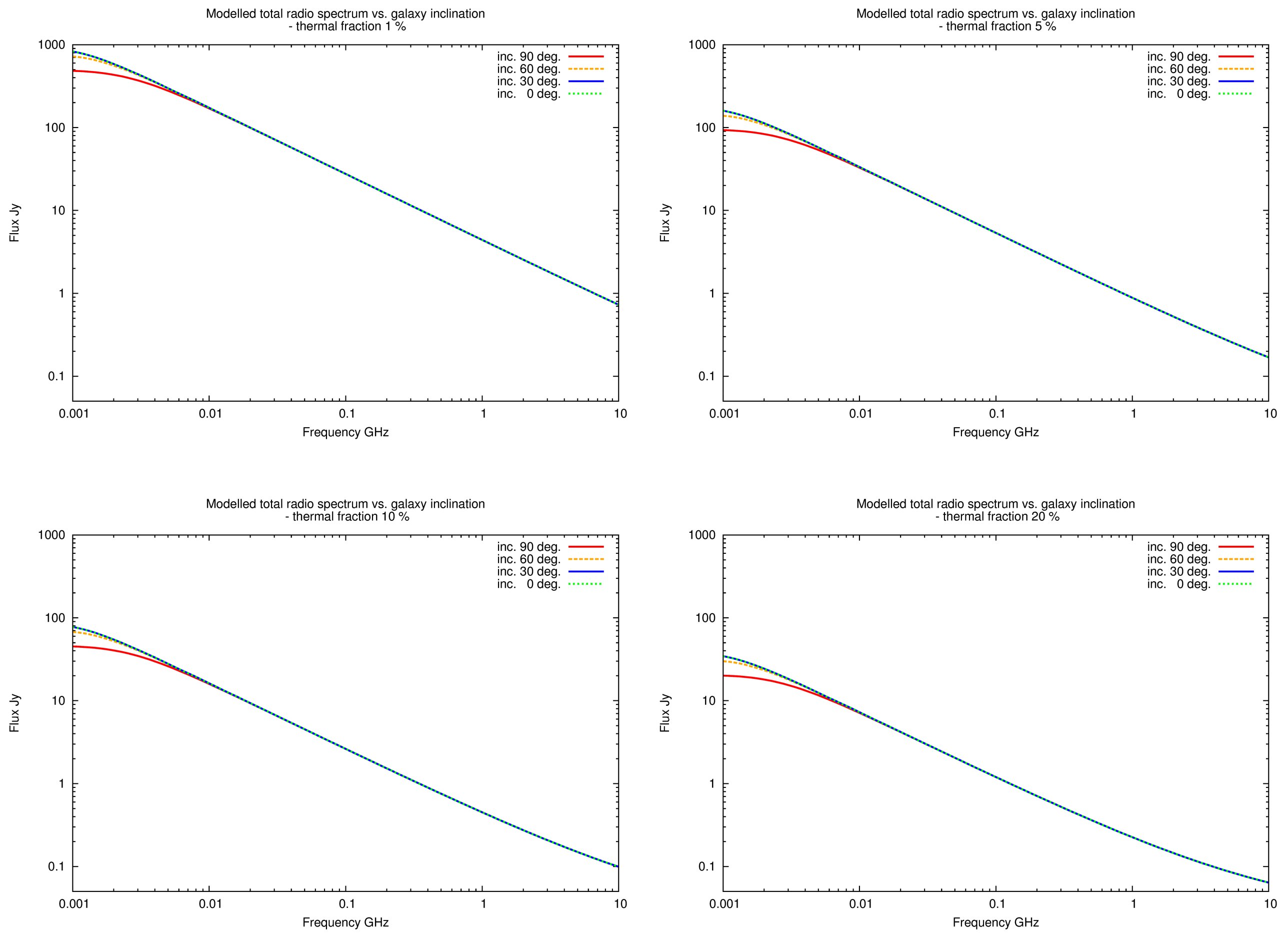

Fig. 1. The modelled total radio spectra of galaxy with thermal fraction of about 1 % , 5%, 10 % (c) and 20 % at 1.0 GHz respectively. The colored lines represent modelled total radio spectrum for different galaxy inclinations (90, 60, 30, 0 deg.) from edge-on galaxies (solid red line) to face-on galaxies (doted-dashed green line).

The thermal emission from ionized gas given by spatial distribution defined in equation (2) provides a theoretical value of total thermal emission based on the theory of free-free emission. The thermal fraction at chosen level are obtained by scaling non-thermal emission (constant C_0 in eq. (1)).

The modelled global radio spectrum of two cases: edge-on and face-on galaxy with different thermal fractions are presented in Figure 2.

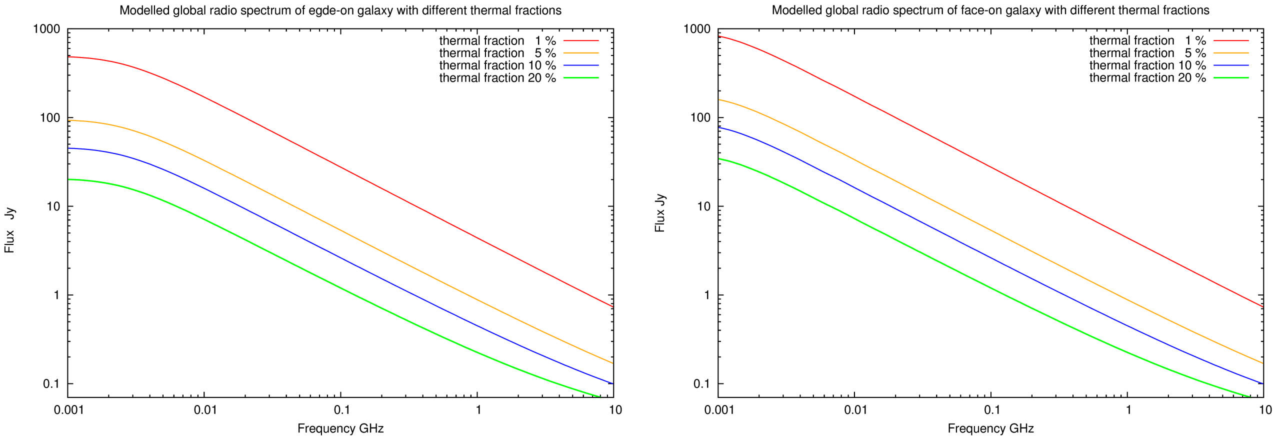

Fig. 2. The modelled total radio spectra of galaxy with thermal fraction of about 1 % , 5%, 10 % and 20 % at 1.0 GHz respectively for edge-on (left panel) and face-on galaxy (right panel). The colored lines represent modelled total radio spectrum for different galaxy thermal fractions.

The center of modelled galaxy is the region with the most extreme characteristics, the highest thermal gas density and non-thermal emission. Obtained from modelling radio spectra from galaxy center for two cases: edge-on and face-on galaxy disc with different thermal fractions are depicted in Figure 3.

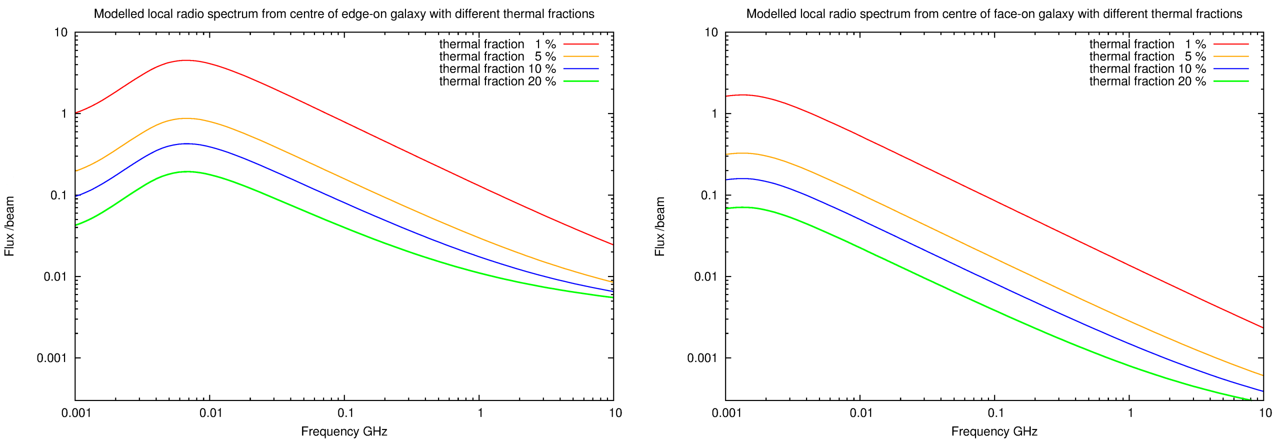

Fig. 3. The modelled local radio spectra from galaxy center with thermal fraction of about 1 % , 5%, 10 % and 20 % at 1.0 GHz respectively for edge-on (left panel) and face-on galaxy (right panel). The colored lines represent modelled total radio spectrum for different galaxy thermal fractions.

4 Discussion and conclusions

Modelling of radio emission from galaxies with spatial distribution of ionized gas and cosmic ray electron similar to the Milky Way are the main subject of this research. In modelling we considered distance of 1 Mpc to galaxy, and frequency range from 1 MHz to 10 GHz. Our aim was to reproduce radio emission in assumed frequency range as it would be observed from the spacecraft without effects of Earth's atmosphere. Observational effect as orientation of galaxy disc along the line of sight was taken into account. Also thermal fraction (thermal emission to total radio emission) of modelled galaxy were considered. Modelling for inclination of galaxy disk 0, 30, 60, 90 degrees were done, and for different thermal fractions: 1%, 5%, 10%, 20%.

In our modelling we assumed action of free-free emission and absorption from ionized gas, synchrotron emission with fixed constant spectral index (-0.8) in each region in galaxy. The inverse Compton losses at higher frequencies are not included due to their low action below 10 GHz in conditions presents in our galaxy model. The synchrotron self-absorption, the ionization losses are also not included in modelling due their weak action in the Milky Way like galaxies modelled by spatial distributions given by eq. (1) and (2).

The modelled global spectra of galaxies with different inclinations and thermal fractions presented in Figure 1. suggest that more fattening than turn-over in global spectra at low radio frequencies are expected. There is a clear evidence that the low frequency part of global radio spectrum is dependent on the galaxy disk orientation to the observer (Figure 2). Flattening of global spectrum is less visible in face-on than edge-on galaxies. There is not also possible to distinguish between global radio spectra from galaxies with inclinations from 0 to 30 deg. range. Above 10 MHz correlation with inclination is disappearing. The shape of low frequency part of moddeled global radio spectrum (below 10 MHz) shows weak correlation with thermal fraction for both egde-on and face-on galaxies. At higher frequencies total spectrum presents well known significant correlation with higher thermal fraction.

The local spectrum from galaxy center in our modelling provides results that there is rather turn-over than flattening as in modelled global radio spectrum. This is in agreement to previous radio observations of the Milky Way. The radio spectrum of the Galaxy has a turn-over at 3 MHz, mostly caused by the free-free absorption in diffuse Warm Ionized Gas (eg. Peterson & Webber 2002 [14]). The shape of low frequency part of local spectrum is significant correlated with inclination of galaxy. Also influence on low frequency local spectrum is more visible in egde-on galaxies, and similar to global spectra thermal fraction modifies shape of spectra more at higher frequencies.

References

1. Klein, U., Emerson, D. T., 1981, A&A, 94, 29
2. Hummel, E., 1981, A&A, 93, 93
3. Gioia, I. M., Gregorini, L., & Klein, U., 1982, A&A, 116, 164
4. Harnett, J. I., 1982, Austr. J. Phys., 35, 321
5. Condon, J. J.:,1987, ApJ Suppl. Ser., 65, 485
6. Niklas, S., 1995, Ph.D. Thesis, University of Bonn
7. Condon, J. J., 1992, ARA&A, 30, 575
8. Israel F., P., Mahoney M., J., 1990, ApJ, 352, 30
9. Hummel, E.: 1991, A&A, 251, 442
10. Condon, J. J., Huang, Z.-P., Yin, Q. F., Thuan, T. X., 1991, ApJ, 378, 65
11. Clemens, M., S., Scaife , A., Vega, O., and Bressan, A. , 2010, MNRAS, 405, 887
12. X. H. Sun1, , W. Reich , A. Waelkens , and T. A. Enßlin, 2008, A&A 477, 573
13. Lyne, A. G., Manchester, R. N., Taylor, J. H., 1985, MNRAS, 213, 613
14. Peterson, J. D., Webber, W. R., 2002, ApJ, 575, 217